National Aeronautics and Space Administration

HEO Overview and Update from Advanced Exploration Systems

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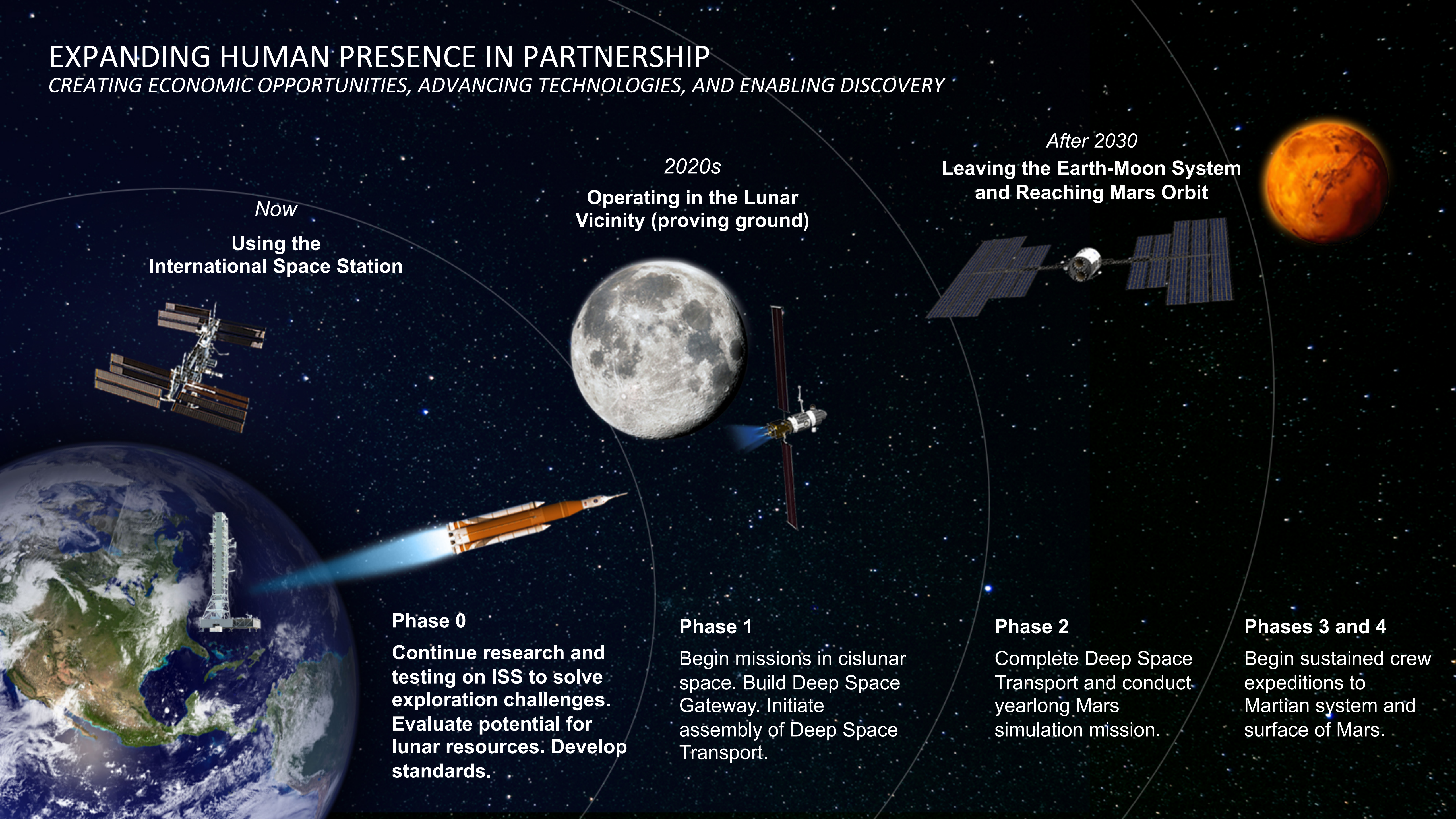

EXPANDING HUMAN PRESENCE IN PARTNERSHIP
CREATING ECONOMIC OPPORTUNITIES, ADVANCING TECHNOLOGIES, AND ENABLING DISCOVERY
Now
Using the International Space Station
2020s
Operating in the Lunar Vicinity (proving ground)
After 2030
Leaving the Earth-Moon System and Reaching Mars Orbit
Phase 0
Continue research and testing on ISS to solve exploration challenges. Evaluate potential for lunar resources. Develop standards.
Phase 1
Begin missions in cislunar space. Build Deep Space Gateway. Initiate assembly of Deep Space Transport.
Phase 2
Complete Deep Space Transport and conduct yearlong Mars simulation mission.
Phases 3 and 4
Begin sustained crew expeditions to Martian system and surface of Mars.

STRATEGIC PRINCIPLES FOR SUSTAINABLE EXPLORATION

- **FISCAL REALISM**
  Implementable in the near-term with the buying power of current budgets and in the longer term with budgets commensurate with economic growth;

- **SCIENTIFIC EXPLORATION**
  Exploration enables science and science enables exploration; leveraging scientific expertise for human exploration of the solar system.

- **TECHNOLOGY PULL AND PUSH**
  Application of high Technology Readiness Level (TRL) technologies for near term missions, while focusing sustained investments on technologies and capabilities to address the challenges of future missions;

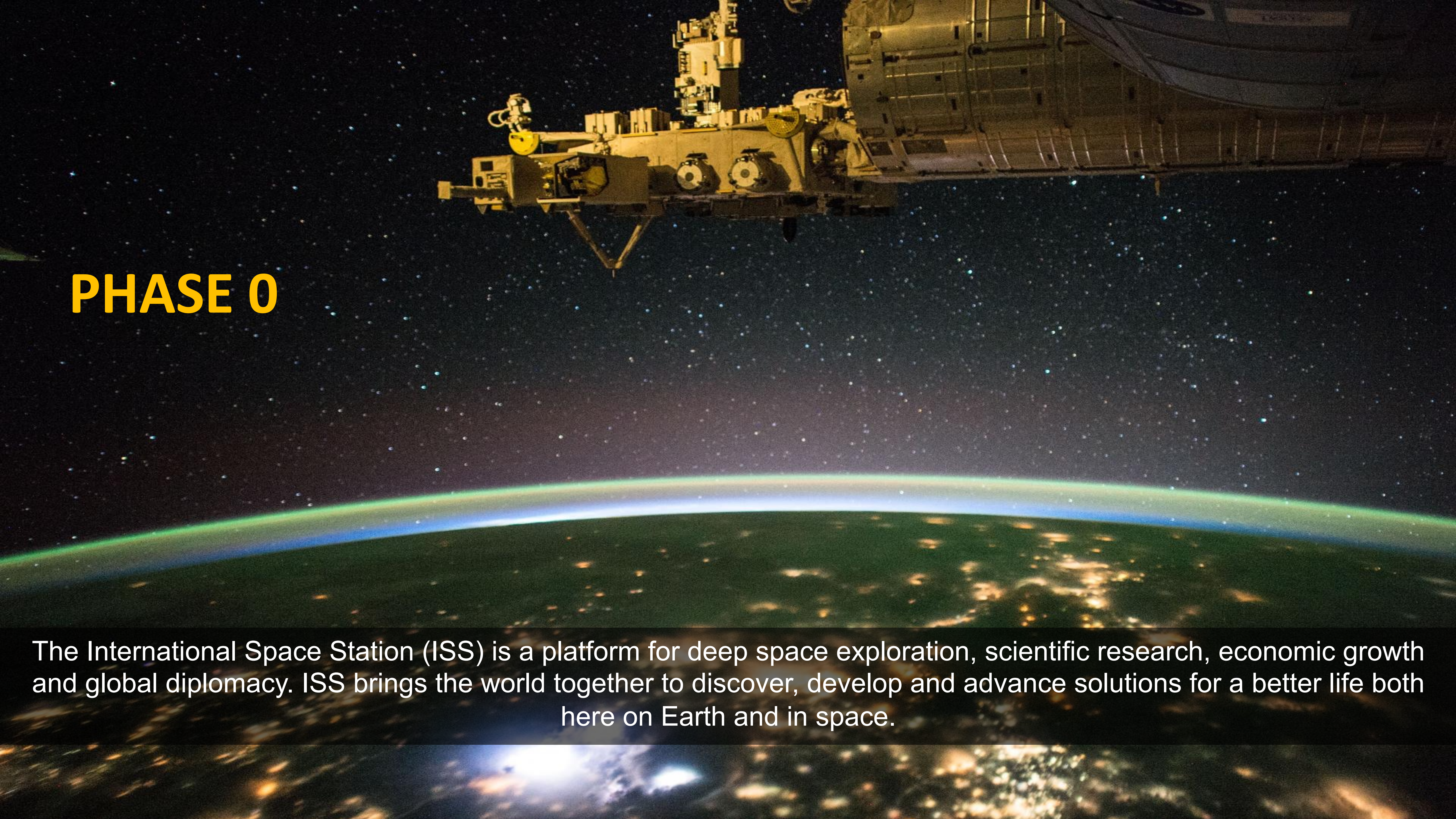
- **GRADUAL BUILD UP OF CAPABILITY**
  Near-term mission opportunities with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time;

- **ECONOMIC OPPORTUNITY**
  Opportunities for U.S. commercial business to further enhance their experience and business base;

- **ARCHITECTURE OPENNESS AND RESILIENCE**
  Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions;

- **GLOBAL COLLABORATION AND LEADERSHIP**
  Substantial new international and commercial partnerships, leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and

- **CONTINUITY OF HUMAN SPACEFLIGHT**
  Uninterrupted expansion of human presence into the solar system by establishing a regular cadence of crewed missions to cis-lunar space during ISS lifetime.



PHASE 0

The International Space Station (ISS) is a platform for deep space exploration, scientific research, economic growth and global diplomacy. ISS brings the world together to discover, develop and advance solutions for a better life both here on Earth and in space.

What Benefits Come from Research on the Space Station?

Enabling Deep Space Exploration

Scientific Discovery

Benefits for Humanity

COMMERCIAL CARGO

** Currently making resupply missions to ISS*

Missions flying to ISS in 2019

COMMERCIAL CREW: AIMING TO LAUNCH ASTRONAUTS FROM THE U.S. BY THE END OF 2018

BOEING

SPACEX

BUILDING BLOCKS TO DEEP SPACE

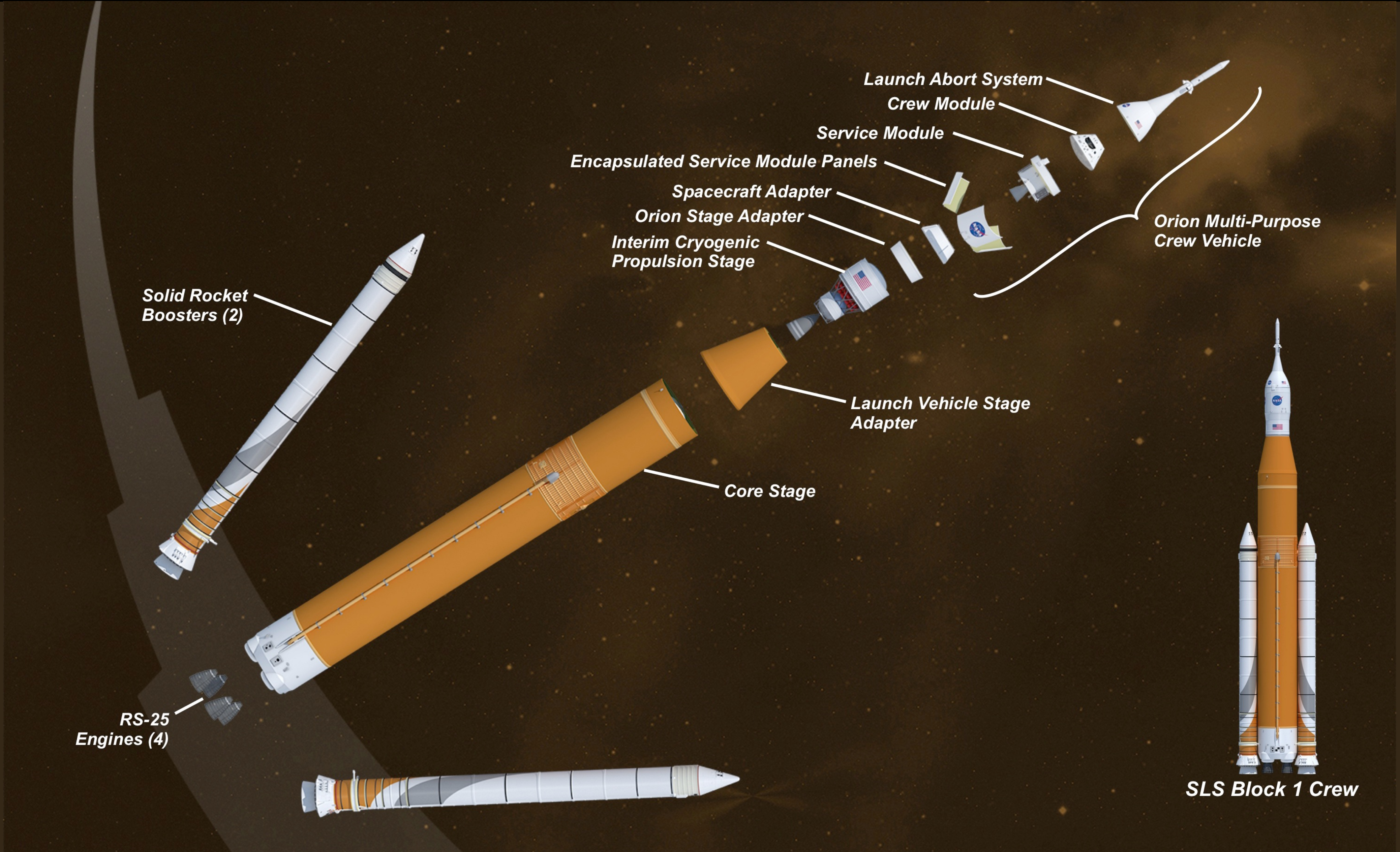
Beginning human exploration beyond LEO as soon as practicable helps secure our future in space.

Orion Spacecraft

Space Launch System

Ground Systems Development & Operations

AMERICA'S NEW SPACE EXPLORATION CAPABILITY:
ORION CREW EXPLORATION VEHICLE & SPACE LAUNCH SYSTEM



Ground Systems Facilities Supporting EM-1

LO2 trucks arrive at Launch Pad 39B

Left-hand forward skirt solid rocket boosters arrive inside the high bay at the BFF

New flame deflector segments installed at Launch Pad 39B

ICPS arrives at Space Station Processing Facility

Core stage forward skirt umbilical installed on mobile launcher

Underway Recovery Test #5

Orion Test and EM-1 Flight Hardware in Production

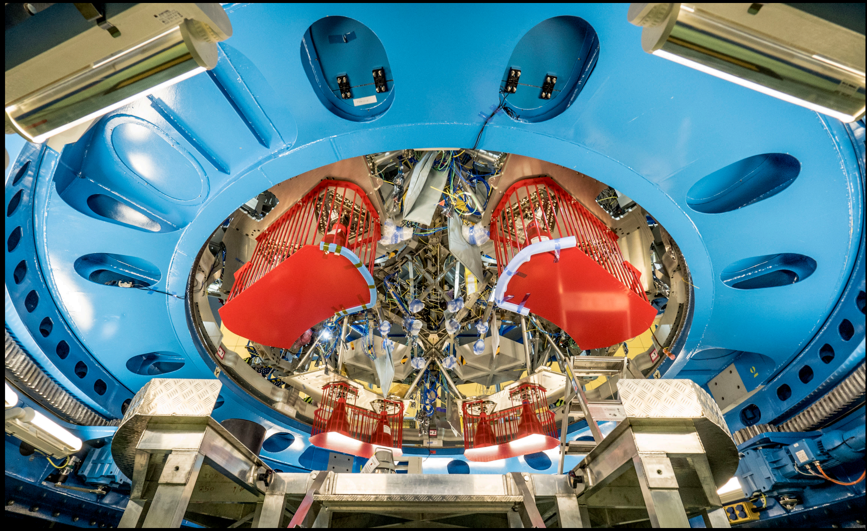
Ogive testing at Plum Brook Station

Initial power on completed successfully

Propulsion Qualification Module installed at White Sands Test Facility

Orion parachute drop tests

Abort motor for launch abort system test fire



ESA service module at Airbus Defense and Space

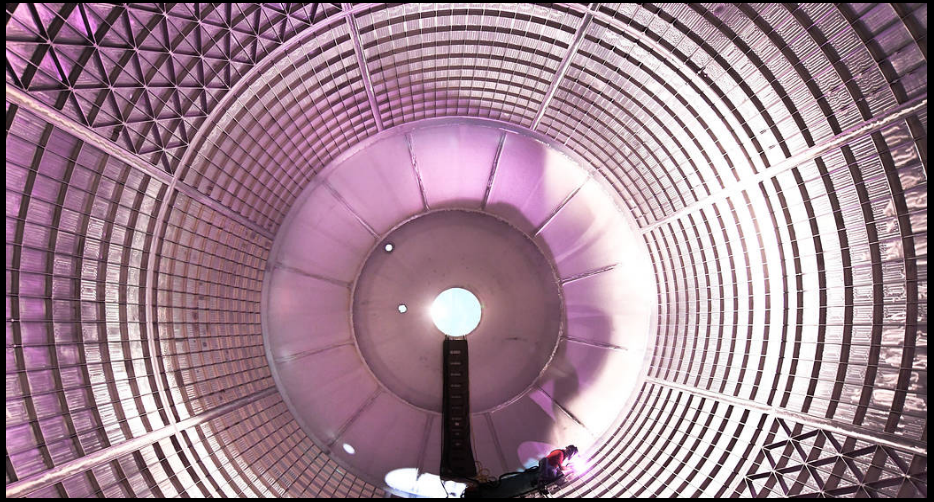
SLS Testing and Flight Hardware in Production

Welding of liquid oxygen tank complete

LVSA ready for thermal insulation application

RS-25 flight controller tests

Photogrammetric markings applied on completed segments



Liquid oxygen tank flight undergoing hydrostatic test

Structure of the intertank assembled at MSFC

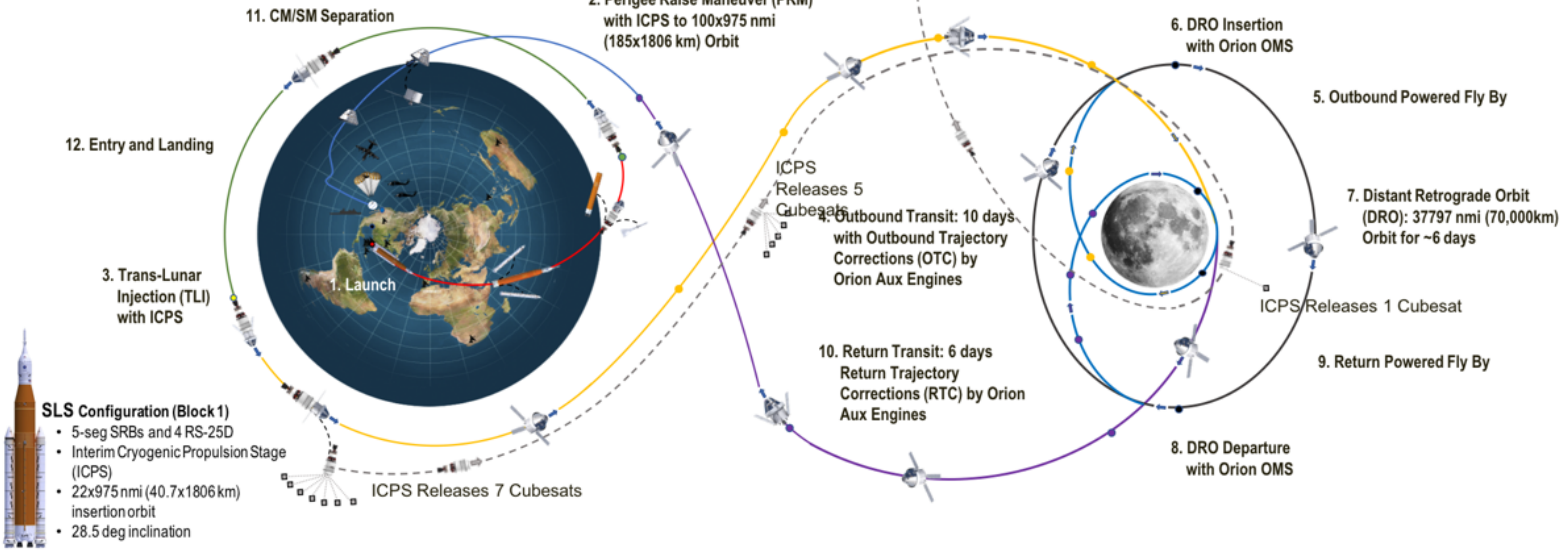
EXPLORATION MISSION 1

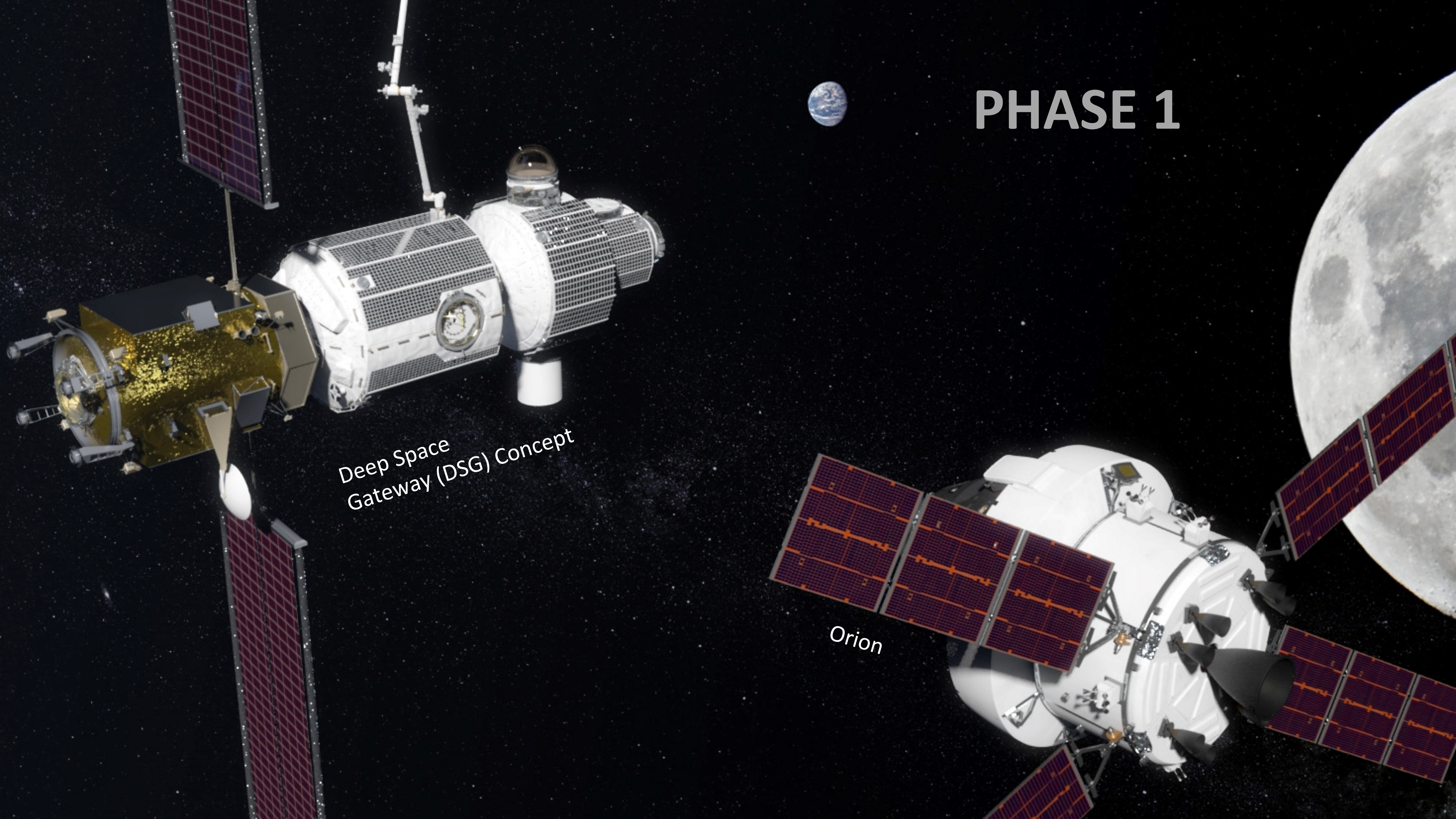
Uncrewed Distant Retrograde Orbit

Total Mission Duration: 25 Days

Baseline Objectives

- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight
- Landing off the coast of California




PHASE 1
Deep Space
Gateway (DSG) Concept
Orion

Phase 1 Plan

Establishing deep-space leadership and preparing for Deep Space Transport development

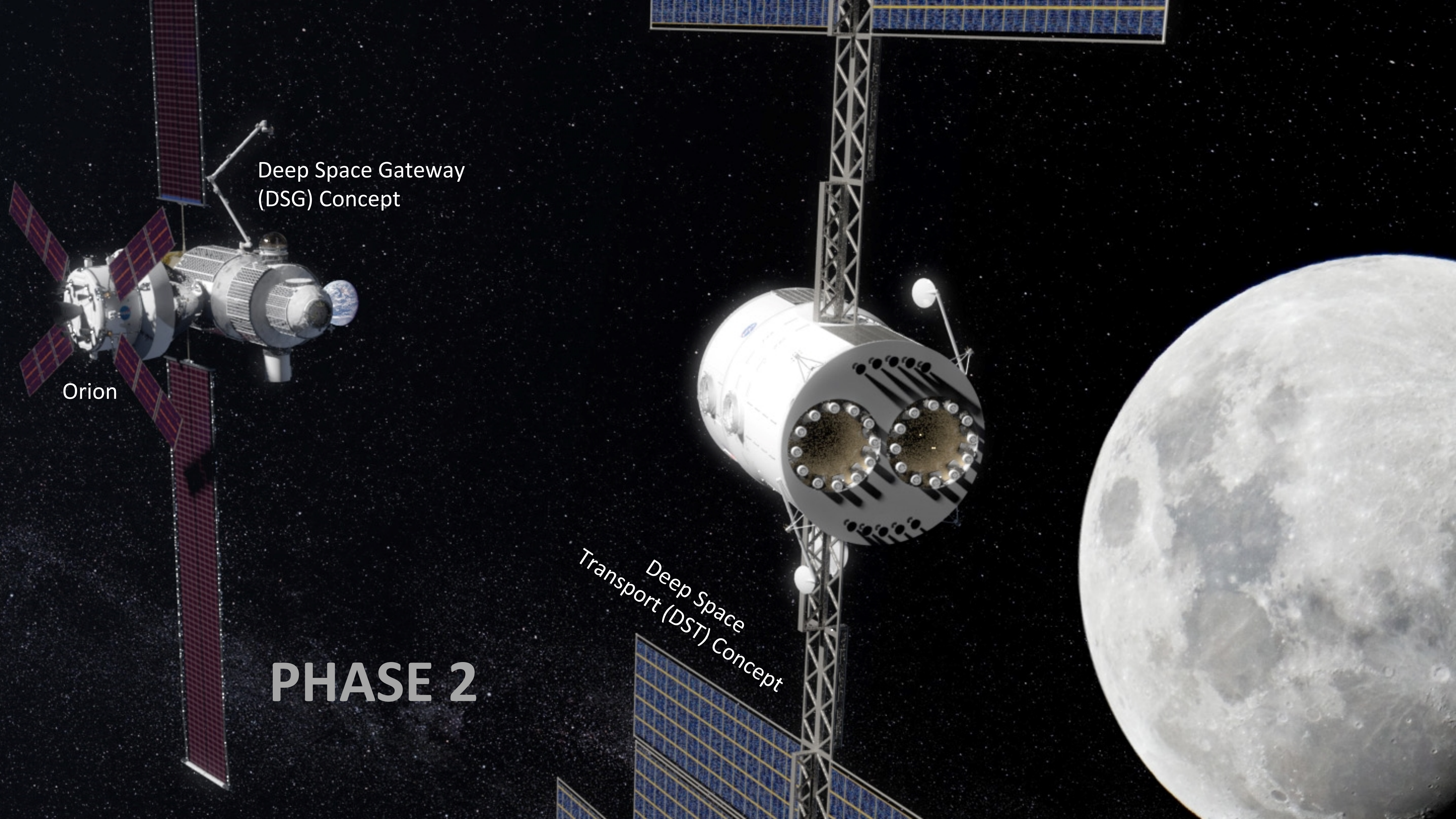
		Deep Space Gateway Buildup			
EM-1	**Europa Clipper**	**EM-2**	**EM-3**	**EM-4**	**EM-5**
2019 - 2025					**2026**
SLS Block 1 Crew: 0	SLS Block 1B Cargo Europa Clipper (subject to approval)	SLS Block 1B Crew: 4 CMP Capability: 8-9T 40kW Power/Prop Bus	SLS Block 1B Crew: 4 CMP Capability: 10mT Habitation	SLS Block 1B Crew: 4 CMP Capability: 10mT Logistics	SLS Block 1B Crew: 4 CPL Capability: 10mT Airlock
Distant Retrograde Orbit (DRO) 26-40 days	Jupiter Direct	Multi-TLI Lunar Free Return 8-21 days	Near Rectilinear Halo Orbit (NRHO) 16-26 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days
Gateway (blue) Configuration (Orion in grey)			Cislunar Support Flight	Cislunar Support Flight	

These essential Gateway elements can support multiple U.S. and international partner objectives in Phase 1 and beyond

Known Parameters:
- Gateway architecture supports Phase 2 and beyond activities
- International and U.S. commercial development of elements and systems
- Gateway will translate uncrewed between cislunar orbits
- Ability to support science objectives in cislunar space

Open Opportunities:
- Order of logistics flights and logistics providers
- Use of logistics modules for available volume
- Ability to support lunar surface missions

- **Assumptions**
  - Deep Space Gateway provides ability to support multiple NASA, U.S. commercial, and international partner objectives in Phase 1 and beyond
  - The Gateway is designed for deep space environments
    - Supports (with Orion docked) crew of 4 for a minimum of 30 days
    - Supports buildup of the Deep Space Transport
- **Emphasis on defining early Phase 1 elements**
  - Gateway Power Propulsion Element
  - Gateway Habitat
  - Logistics Strategy
- **Future work to refine later elements; early feasibility trades complete**
  - Airlock
  - Deep Space Transport


Deep Space Gateway
(DSG) Concept
Orion
Deep Space
Transport (DST) Concept
PHASE 2

(PLANNING REFERENCE) Phase 2 and Phase 3

Looking ahead to the shakedown cruise and the first crewed missions to Mars

Transport Delivery		Transport Shakedown		Mars Transit	
EM-6	EM-7	EM-8	EM-9	EM-10	EM-11
2027		2028 / 2029		2030+	
SLS Block 1B Cargo P/L Capability: 41t TLI	SLS Block 1B Crew: 4 CMP Capability: 10t	SLS Block 1B Cargo P/L Capability: 41t TLI	SLS Block 2 Crew: 4 CMP Capability: 13+t	SLS Block 2 Cargo P/L Capability: 45t TLI	SLS Block 2 Crew: 4 CMP Capability: 13+t
Deep Space Transport	Logistics	DST Logistics & Refueling	Logistics	DST Logistics & Refueling	Logistics
DST checkout in NRHO 191-221 days Cislunar Support Flight		DSG: continued operations in cislunar space DST: shakedown in cislunar space with return to DSG in NRHO 300-400 days Cislunar Support Flight		DSG: continued operations in cislunar space DST: Mars transit and return to DSG in NRHO Cislunar Support Flight	

Reusable Deep Space Transport supports repeated crewed missions to the Mars vicinity

Known Parameters:

- DST launch on one SLS cargo flight
- DST shakedown cruise by 2029
- DST supported by a mix of logistics flights for both shakedown and transit
- Ability to support science objectives in cislunar space

Open Opportunities:

- Order of logistics flights and logistics providers
- Shakedown cruise vehicle configuration and destination/s
- Ability to support lunar surface missions

- **Assumptions**
  - Deep Space Transport provides habitation and transportation needs for transporting crew into deep space including supporting human Mars-class missions
  - The Transport system life will be designed for
    - Reuse for 3 Mars-class missions with resupply and minimal maintenance
    - Crew of 4 for 1,000 day-class missions in deep space
    - Launch on one SLS 1B cargo vehicle - resupply and minimal outfitting to be performed in cislunar space
- **Emphasis on supporting shakedown cruise by 2029**
  - Shakedown cruise to be performed in lunar vicinity
  - Utilizes deep space interfaces and common design standards
- **Future work trades**
  - Shakedown cruise objectives
  - Mars reference mission functional requirements

DSG&T CONCEPT MATURATION ACTIVITIES

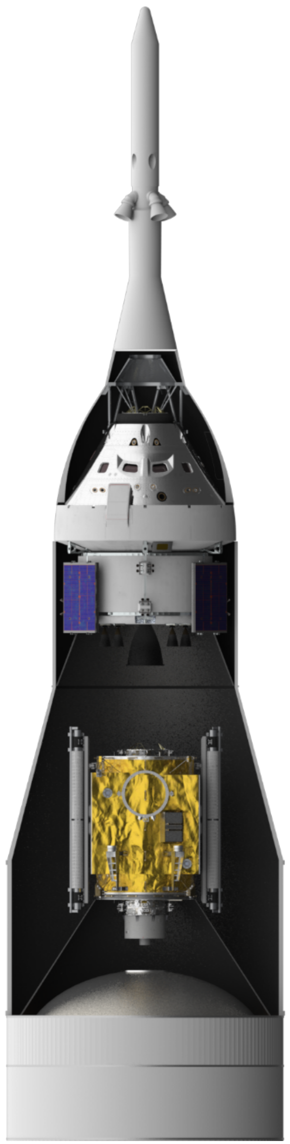
To inform decision making of DSG&T consistent with a delivery of the Power/Propulsion Element (PPE) for launch as a co-manifested payload on EM-2, HEOMD is leading the development and maturation of the following products through the fall/winter of 2017:

- High level **Exploration Objectives**. Initially baselined in September 2016; updated in June 2017. Establishes 60 objectives in phases 0, and 1, and 2 timeframes. Discussions ongoing with international partners for opportunities to align U.S. and partner deep space exploration objectives.
- **Interoperability Standards** that provide a comprehensive set of HEOMD-level requirements necessary to certify the DSG&T for deep space missions.
- **Exploration Requirements** and **Design Concept of Operations** that captures the HEO-level requirements and design conops for the systems we are building to implement Exploration Objectives. Evolving Exploration Systems Development requirements to include DSG&T requirements and reflect SLS and Orion support for DSG&T buildup.
- **Utilization Plan** that defines how and when we will use the systems, mission by mission, and what capabilities and resources are provided to support civilian, commercial, and international partner utilization of the DSG&T.

To ensure consistent coordination and communication across all exploration activities, these products are configuration controlled at the HEOMD level consistent with the **HEOMD configuration management process.**

Power & Propulsion: 1st Element in Gateway Concept

- **Start deep space gateway when we fly crew to vicinity of the moon**
- **A power propulsion element (PPE) would be the first element in a cislunar gateway**
- **The PPE would provide key functionality for the DSG including**
  - power to DSG and externally accommodated elements
  - transportation for the DSG between cislunar orbits
  - orbital maintenance as needed
  - attitude control for the DSG in multiple configurations with and without visiting vehicles such as Orion
  - communications with Earth, space to space communications, and radio frequency relay capability in support of extra-vehicular activity (EVA) communications.
- **PPE will launch co-manifested with Orion crew vehicle on the Space Launch System for the EM-2 flight**



Approach to PPE Development

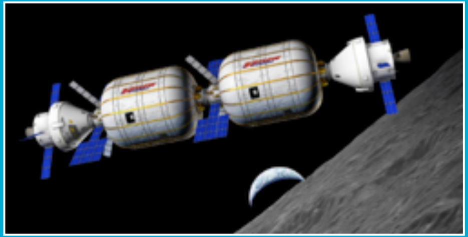
- **PPE will leverage advanced solar electric propulsion (SEP) technologies developed and matured during Asteroid Redirect Mission activities:**
  – Directly use commercially available U.S. flight hardware
  – Infuse advanced SEP technology developed by NASA's Space Technology Mission Directorate
  – Align with U.S. industry plans for future use of SEP
  – Accommodate international and/or commercial partner provided capabilities

NEXTSTEP HABITATION OVERVIEW

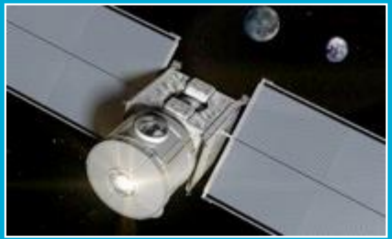
NextSTEP Phase 1: 2015-2016

Cislunar habitation concepts that leverage commercialization plans for LEO


LOCKHEED MARTIN


BIGELOW AEROSPACE


ORBITAL ATK


BOEING

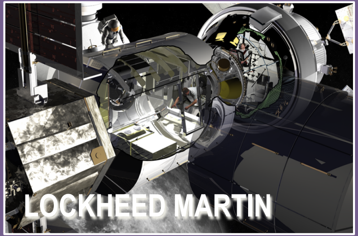
FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

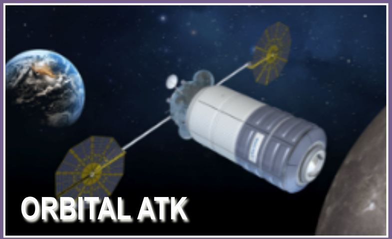
Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

NextSTEP Phase 2: 2016-2018

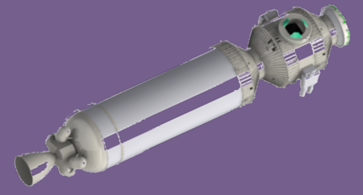
- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

FIVE GROUND PROTOTYPES BY 2018





ONE CONCEPT STUDY


NANORACKS

Define reference habitat architecture in preparation for Phase 3.

Initial discussions with international partners

Phase 3: 2018+

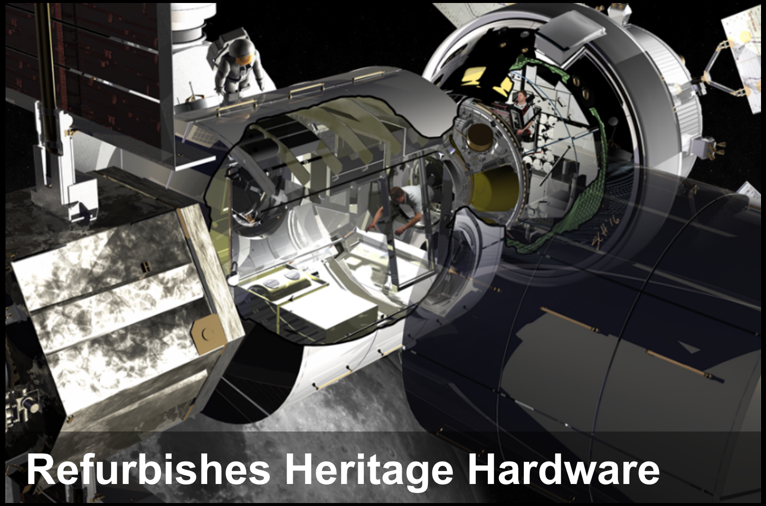
- Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)

FULL-SIZED GROUND PROTOTYPE DEVELOPMENT

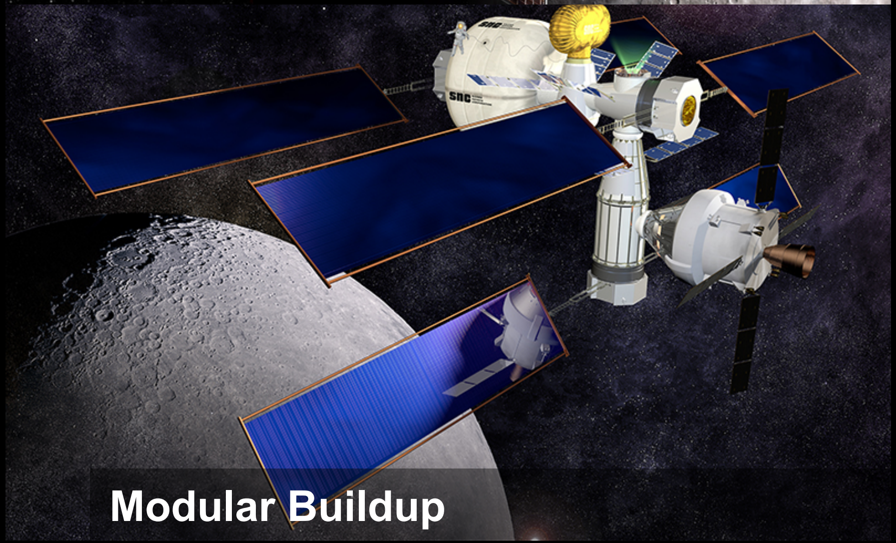
DIFFERENT APPROACHES FOR BROAD TRADE SPACE OF OPTIONS

Expandable

Leverages Existing Technologies



Refurbishes Heritage Hardware



Modular Buildup

Builds on proven cargo spacecraft development

DEEP SPACE HABITATION SYSTEMS

Habitation Systems Elements

	Habitation Systems Elements	TODAY Space Station	FUTURE Deep Space
LIFE SUPPORT	Excursions from Earth are possible with artificially produced breathing air, drinking water and other conditions for survival. Atmosphere Management Water Management Waste Management	42% O_2 Recovery from CO_2 90% H_2O Recovery < 6 mo mean time before failure (for some components)	75%+ O_2 Recovery from CO_2 98%+ H_2O Recovery >30 mo mean time before failure
ENVIRONMENTAL MONITORING	NASA living spaces are designed with controls and integrity that ensure the comfort and safety of inhabitants. Pressure O_2 & N_2 Moisture Particles Microbes Chemicals Sound	Limited, crew-intensive on-board capability Reliance on sample return to Earth for analysis	On-board analysis capability with no sample return Identify and quantify species and organisms in air & water
CREW HEALTH	Astronauts are provided tools to perform successfully while preserving their well-being and long-term health. Monitoring Exercise Diagnostics Treatment Food Storage & Management	Bulky fitness equipment Limited medical capability Frequent food system resupply	Smaller, efficient equipment Onboard medical capability Long-duration food system
EVA: EXTRA-VEHICULAR ACTIVITY	Long-term exploration depends on the ability to physically investigate the unknown for resources and knowledge. Mobility Life Support Science and Exploration	High upper body mobility for limited sizing range Low interval between maintenance, contamination sensitive, and consumables limit EVA time Construction and repair focused tools; excessive inventory of unique tools	Full body mobility for expanded sizing range Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time Geological sampling and surveying equipment; common generic tool kit

DEEP SPACE HABITATION SYSTEMS

Habitation Systems Elements

TODAY Space Station

FUTURE Deep Space

RADIATION PROTECTION

During each journey, radiation from the sun and other sources poses a significant threat to humans and spacecraft.

Monitoring — Tracking — Modeling — Mitigation

Today (Space Station):
- Node 2 crew quarters (CQ) with polyethylene reduce impacts of proton irradiation.
- Large multi-layer detectors & small pixel detectors – real-time dosimetry, environment monitoring, tracking, model validation & verification
- Bulky gas-based detectors – real-time dosimetry
- Small solid-state crystal detectors – passive dosimetry (analyzed post-mission)

Future (Deep Space):
- Solar particle event storm shelter, optimized position of on-board materials and CQ
- Small distributed pixel detector systems – real-time dosimetry, environment monitoring, and tracking
- Small actively read-out detectors for crew – real-time dosimetry

FIRE SAFETY

Throughout every mission, NASA is committed to minimizing critical risks to human safety.

Detection — Protection — Suppression — Cleanup

Today (Space Station):
- Large CO_2 Suppressant Tanks
- 2-cartridge mask
- Obsolete combustion prod. sensor
- Only depress/repress clean-up

Future (Deep Space):
- Water Mist portable fire extinguisher
- Single Cartridge Mask
- Exploration combustion product monitor
- Smoke eater

LOGISTICS

Sustainable living outside of Earth requires explorers to reduce, recycle, reuse, and repurpose materials.

Tracking — Clothing — Packaging — Trash

Today (Space Station):
- Manual scans, displaced items
- Disposable cotton clothing
- Packaging disposed
- Bag and discard

Future (Deep Space):
- Automatic, autonomous RFID
- Long-wear clothing/laundry
- Bags/foam repurposed w/3D printer
- Resource recovery, then disposal

CROSS-CUTTING

Powerful, efficient, and safe launch systems will protect and deliver crews and materials across new horizons.

Robotics — Power — Communication — Docking — Avionics, Autonomy & Software — Thermal — Materials

Today (Space Station):
- Minimal on-board autonomy
- Near-continuous ground-crew communications
- Some common interfaces, modules controlled separately

Future (Deep Space):
- Ops independent of Earth & crew
- Up to 40-minute comm delay
- Widespread common interfaces, modules/systems integrated
- Manufacture replacement parts in space

NASA

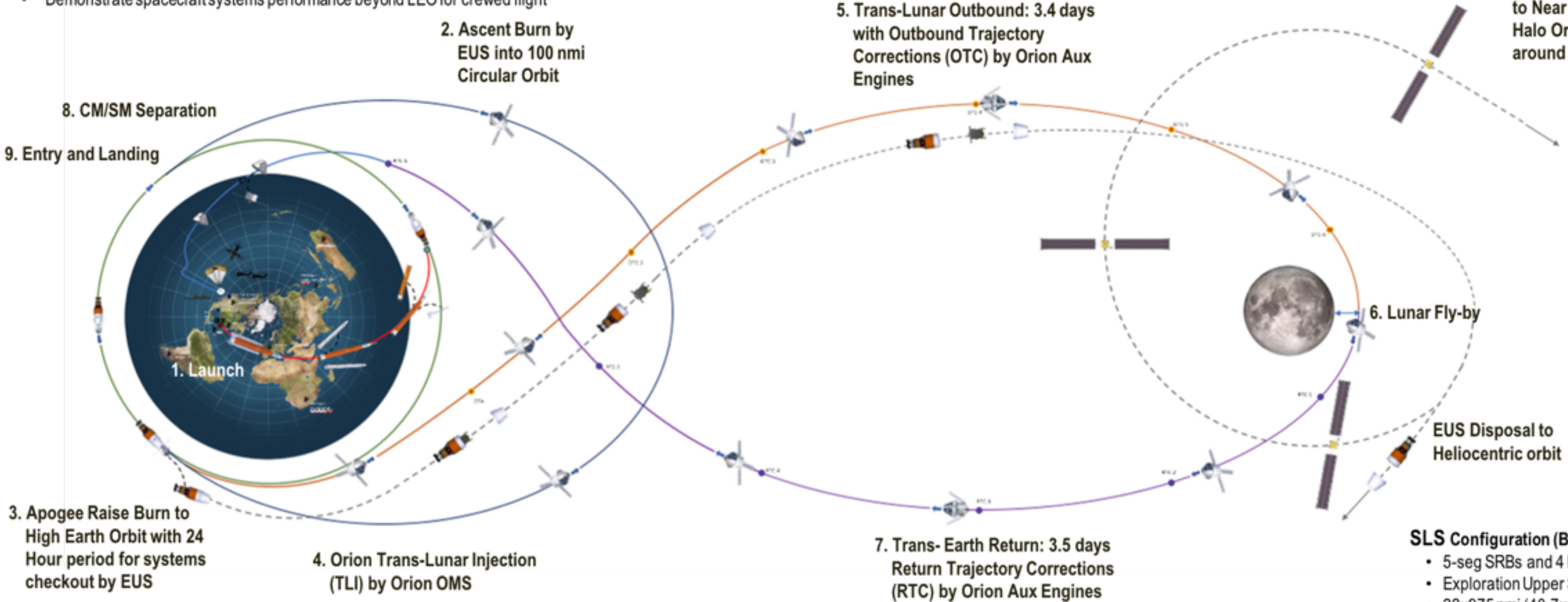
EXPLORATION MISSION 2

Crewed Multi-Trans Lunar Injection Free with DSG PPE

Total Mission Duration: 9 Days

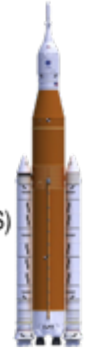
Baseline Objective

- Demonstrate spacecraft systems performance beyond LEO for crewed flight



SLS Configuration (Block 1B)

- 5-seg SRBs and 4 RS-25D
- Exploration Upper Stage (EUS)
- 22x975 nmi (40.7x1806 km) insertion orbit
- 28.5 deg inclination



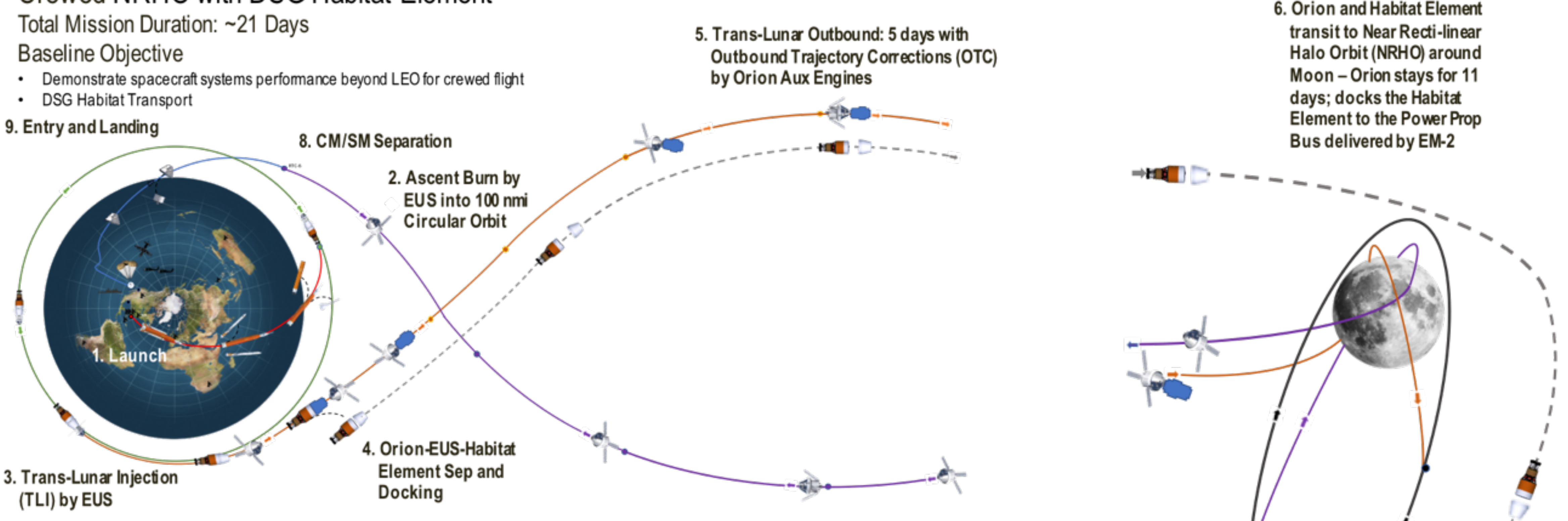
EXPLORATION MISSION 3

Crewed NRHO with DSG Habitat Element

Total Mission Duration: ~21 Days

Baseline Objective

- Demonstrate spacecraft systems performance beyond LEO for crewed flight
- DSG Habitat Transport



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